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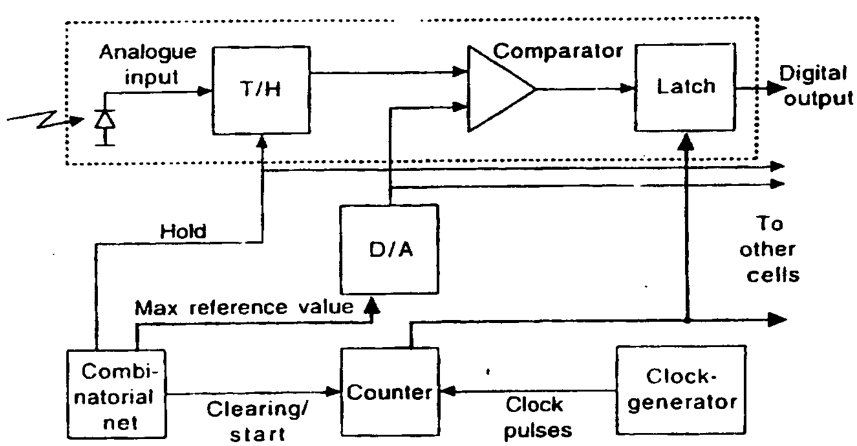
(54) Title: INTEGRATING A/D CONVERTER AND RADIATION-SENSITIVE SENSOR DEVICE COMPRISING SUCH A CONVERTER



(57) Abstract

The present invention relates to an integrating A/D converter and a radiation-sensitive sensor device comprising such a converter. The A/D converter comprises an integrating element, which during fixed time intervals integrates an input signal, and further a comparator, to the one input of which said integrated value is continuously supplied and to the other input of which a reference value is supplied, and a device comprising a clock pulse generator, which supplies a counter, which during said time intervals counts upwards or downwards from a starting value, and which, based on the output signal from the comparator, determines whether the integrated signal in upwards counting exceeds or equals the reference value and in downwards counting is lower than or equals the reference value and, if so, at which point of time in the time interval, which is a measure of the size of the signal.

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Integrating A/D Converter and Radiation-Sensitive Sensor Device comprising such a Converter

The present invention relates to an integrating A/D converter and a radiation-sensitive sensor device comprising such a converter. More specifically it concerns converters of that sort which can determine the strength of a signal over a much greater interval than those which prior art such converters can manage.

The background of the invention are optical sensor devices, which under highly varying intensity conditions will be saturated in known designs. However, the principle can also be used in other integrating A/D converters, which are thus also comprised by the invention. Nevertheless, the invention will be described in connection with optical sensors.

The dynamic range of a radiation-sensitive sensor is normally restricted upwards by the maximum intensity that can be detected without its maximum reading value being exceeded. For a given resolution, in the case of digital sensors, the range is besides restricted upwards by the greatest digital value that can be expressed with the given number of bits that are available.

An ordinary mode of function of a radiation-sensitive sensor is that a photodiode is illuminated and the thus generated current is integrated in an element, e.g. a capacitor, during the time of exposure. After the time of exposure, the value can be read and/or be A/D converted.

In the A/D conversion, use is often made of a circuit solution, which means that after completion of the exposure, a counter emits a sequence of gradually increasing digital values, which are converted into analogue values and which are subsequently compared with the exposure value that was generated during the last exposure. When the value of the counter is equal to or greater than the exposure value, the digital value is stored as the value that corresponds to the analogue exposure value.

In many applications, prior-art sensor devices as those mentioned above cannot measure over a sufficiently great intensity range. An example of measuring tasks that cause problems is the watching, by means of an image-generating sensor, of objects having very different radiation intensity in various parts. A missile with a trailing jet can be mentioned as an example. It may very well be the case that both

the shape of the missile, which is given with low radiation intensity, and the structure of the flame, which is given with high intensity, are important. It is not possible to measure these two matters at the same time while using prior-art detector matrices. It is necessary to measure periodically with different exposure time.

A device will be described below, the application of which permits detection of and quantification of the size of exposure values and other input signals, whose amplitudes are much greater than the maximum value which can be handled by prior-art sensors. This is done by giving it the design as defined in the accompanying claims.

The invention can also be used in very rapid adaptation of exposure time to changed illumination since it is possible to immediately obtain a good measure of how much a sensor has suddenly been overexposed in the classic measuring range. A sensor according to the invention is also extremely suited for anti sensor laser detection since the sensor registers amplitudes although the measured values should normally cause an indication that the sensor has been saturated.

The invention will now be described in more detail with reference to the accompanying drawings, in which

- Fig. 1 shows a prior-art A/D converter,
- Fig. 2 shows a graph of "afterExpAD" with n=3,
- Fig. 3 illustrates an embodiment of an inventive A/D converter,
- Fig. 4 shows a graph of "duringExpAD" with n=3 for a combined A/D converter according to the invention, and
- Fig. 5 shows an embodiment of a combined A/D converter according to the invention.

Fig. 1 shows a prior-art A/D converter. The parts appearing in the box are repeated for each cell whereas the parts situated outside are common. The A/D converter comprises a light-sensitive cell which is cleared and subjected to exposure. During exposure, the value corresponding to the intensity integrated during exposure increases. This value is stated in the Figure as "Analogue input". When the exposure time has been achieved, a hold signal is emitted from the control electronics such that the analogue signal is sampled and held in the S/H circuit. At the same time, the counter is cleared and begins to count upwards. The digital values of the counter are converted into analogue values in a D/A converter. The two analogue values are compared in a comparator, and if the values are found to be equal or if

the hold value is smaller than the value of the counter in analogue form, this counter value is stored in digital form as the digital value of the intensity. This type of A/D conversion is below called *"afterExpAD"*.

Fig. 2 shows the ratio of the digital value from the A/D conversion, DV_{AD}, to the exposure value of the time t_{exp}, $E(t_{exp})$. The Figure illustrates the appearance of the graph when *"afterExpAD"* is applied and the number of bits n equals 3. Usually, more bits are used, for instance 8. As will be seen in Fig. 2, only exposure values smaller than $E_{ADmax}(t_{exp})$ can be distinguished. This type of A/D converter can define, with n bits, an intensity value of at most 2^n-1. The value 2^n-1 will below be called "maximum reference value".

An A/D converter that does not suffer from the above-mentioned drawback can function as follows, see also Fig. 3. The parts appearing in the box are repeated for each cell whereas the parts situated outside are common. When the exposure is to begin, the counter is cleared and begins to count upwards. It is of course conceivable to count downwards instead, starting from a fixed starting value. This is also possible in connection with the prior-art A/D converter according to Fig. 1. It is obvious to imagine that the counter is supplied with a constant clock frequency, the period of which together with the maximum number of steps of the counter determine the length of the exposure time. However, it is also conceivable to let the clock frequency vary during the counting procedure. The rising value is supplied to the comparator from the integrating cell directly without any hold, i.e. tracking. A reference value is supplied to the second input of the comparator. In the first place, it is possible to use the maximum reference value according to the above example. For specific applications, for instance when a new exposure time is to be selected quickly, it is possible to use a fraction of the maximum reference value, for instance a fourth or an eighth of the maximum reference value. If the comparator finds equality before the end of the exposure time, the exposure time that has passed since the clearing is a measure of the intensity, and therefore the size of the counter value is a measure of the intensity. This mode of A/D conversion as described above is below called *"duringExpAD"*.

To permit measuring over a complete interval from the intensity zero and far above the normal saturation limit - the maximum reference value - it is possible to use one A/D converter of the *"afterExpAD"* type and one of the *"duringExpAD"* type. When studying Figs 1 and 3, it will be seen that a great part of the components included are common in an A/D converter of the two types. It is therefore easy to arrange a

device sharing these components and having a switching device which switches between the two types.

Fig. 4 shows what the ratio of the digital value from the A/D conversion, DV_{AD}, to the exposure value of the time t_{exp} $E(t_{exp})$ can look like when the A/D conversion process *"duringExpAD"* according to the present invention is combined with, for instance, *"afterExpAD"*. If the exposure value is smaller than or equals $E_{ADmax}(t_{exp})$, *"afterExpAD"* is applied. If the exposure value is greater than $E_{ADmax}(t_{exp})$, *"duringExpAD"* is applied.

The digital value, DV_{AD}, can in ordinary A/D conversion assume values between 0 and 2^n-1. In *"duringExpAD"*, use is made of the same binary digit as in *"afterExpAD"*, but in this context they will have a different meaning. In Fig. 4, DV_{AD} assumes values from 2^n-1 to 0 with *"duringExpAD"*.

It is possible to concretely design such combined A/D converters in a number of different ways. Three are here to be mentioned, called A, B and C, which use a fixed exposure time and one called D, which has a selectable exposure time.

A: During the exposure phase, *"duringExpAD"* is used. When the exposure is completed, a change is made to any of the known forms of conversion, for instance *"afterExpAD"*, provided that it would be found that no storage took place during the exposure interval. This results in different output values depending on whether the exposure value was greater or smaller than the maximum reference value. In case of ambiguity regarding which method has been used, and consequently, which intensity has been available, a check bit can be added for unambiguous determination of the exposure value. See also Fig. 5. The parts appearing in the box are repeated for each cell whereas those situated outside are common.

B: As above, but with reading directly after exposure, which will then show the digital value corresponding to the maximum reference value, provided that the exposure value was smaller than the maximum reference value and that the output register was cleared as the counter was cleared. In this case, the extra bit is not necessary.

C: To be able to use the sensitivity as much as possible, it is possible to proceed as follows instead. An exposure takes place as usual, but this time the logic does not wait for the A/D conversion to be completed, but begins its exposure for the

next image directly according to a prior-art method. This means that the conversion of the exposed intensity value according to the inventive method *"duringExpAD"* takes place at the same time as conversion of the preceding exposed value takes place according to a prior-art method, for example *"afterExpAD"*. To permit application of such a method, there must be an additional counter, an additional comparator and an additional register. Since in this case use is made of two separate registers, it is not necessary to use an additional bit, but the register address is sufficient to determine which measuring method yields a usable measuring result.

D: As above, but permitting a variable clock frequency and an arbitrary maximum reference value to be selected. It is necessary to carry out more extensive calculation work to determine the optimal maximum reference value and the optimal clock frequency since they are a function of each other. If it should turn out that the calculation work should be critical in time, the values can be tabulated since their number is limited. The resolution in exposure time is the factor that determines the number of values, but the resolution need not be too great since the exposure time is calculated as an estimate of the light that will arise. A perfect optimisation of the exposure time requires that the exposure value be known, but if it were known, it need not be measured.

If selecting, for instance, to let the clock pulses come at gradually decreasing intervals, the linearity of the graph in Fig. 4 increases. If the pulses are allowed to have a logarithmic distribution, the graph will be linear.

Claims:

1. An integrating A/D converter comprising an integrating element, which during fixed time intervals integrates an input signal, c h a r a c t e r i s e d in that it further comprises a comparator, to the one input of which said integrated value is continuously supplied and to the other input of which a reference value is supplied, and a device comprising a clock pulse generator, which supplies a counter, which during said time intervals counts upwards or downwards from a starting value, and which, based on the output signal from the comparator, determines whether the integrated signal, in upwards counting, exceeds or is equal to the reference value and, in downwards counting, is lower than or equal to the reference value and, if so, at which point of time in the time interval, which is a measure of the size of the signal.

2. A radiation-sensitive sensor device comprising an integrating A/D converter, which comprises a radiation-sensitive element and an integrating element, which during fixed time intervals integrates the signal from the radiation-sensitive element, c h a r a c t e r i s e d in that it further comprises a comparator, to the one input of which said integrated value is continuously supplied and to the other input of which a reference value is supplied, and a device comprising a clock pulse generator, which supplies a counter, which during said time intervals counts upwards or downwards from a starting value, and which, based on the output signal from the comparator, determines whether the integrated signal, in upwards counting, exceeds or is equal to the reference value and, in downwards counting, is lower than or equal to the reference value and, if so, at which point of time in the time interval, which is a measure of the size of the signal.

3. A radiation-sensitive sensor device as claimed in claim 2, c h a r a c t e r i s e d in that it comprises an array of radiation-sensitive detectors with one comparator for each detector, which have a common clock pulse generator and a common counter.

4. A device as claimed in any one of the preceding claims, c h a r a c t e r i s e d in that it also comprises a second integrating A/D converter, which comprises an integrating element, which during fixed time intervals integrates said input signal, said second integrating A/D converter comprising a comparator, to the one input of which said integrated value is supplied after each time interval and to the other input of which a counter value is supplied in analogue form from a counter,

which during said time intervals counts upwards or downwards from a starting value, the counter being supplied from a clock pulse generator, and a device which, based on the output signal from the comparator, determines whether the value from the counter, in upwards counting, exceeds or is equal to the integrated signal and, in downwards counting, is lower than or equal to the integrated signal and, if so, at which point of time in the time interval, which is a measure of the size of the signal.

5. A device as claimed in claim 4, c h a r a c t e r i s e d in that the first and the second integrating A/D converter comprise substantially common components, and that it comprises a switch which during the time intervals conducts the reference value to the comparator and the value of the counter to the device which determines the point of time when, if at all, the integrated value supplied to the comparator reaches the reference value, and which after the time intervals supplies the value of the counter to one input of the comparator and to the device which determines the point of time when, if at all, the value of the counter reaches the integrated value supplied to the comparator.

6. A device as claimed in claim 5, c h a r a c t e r i s e d in that both the first and the second A/D converter are adapted to measure the intensity during time intervals directly succeeding each other, the first A/D converter measuring the intensity during the current interval whereas the second at the same time measures the intensity during the very time interval before, which is rendered possible, inter alia, by the device comprising a second set of counter, comparator and register, and a switch.

7. A device as claimed in any one of claims 3-6, c h a r a c t e r i s e d in that the clock pulse generation is adapted to supply different pulse frequencies to the first and the second A/D converter.

8. A device as claimed in any one of claims 3-7, c h a r a c t e r i s e d in that to the first A/D converter, the clock pulses are supplied with a frequency changing during the exposure.

9. A device as claimed in any one of claims 3-8, c h a r a c t e r i s e d in that the reference value is a maximum reference value, which corresponds to 2^n-1, where n relates to the number of bits of the A/D converter.

10. A device as claimed in any one of claims 3-8, characterised in that the reference value is a fraction of a maximum reference value, which later corresponds to 2^n-1, where n relates to the number of bits of the A/D converter.

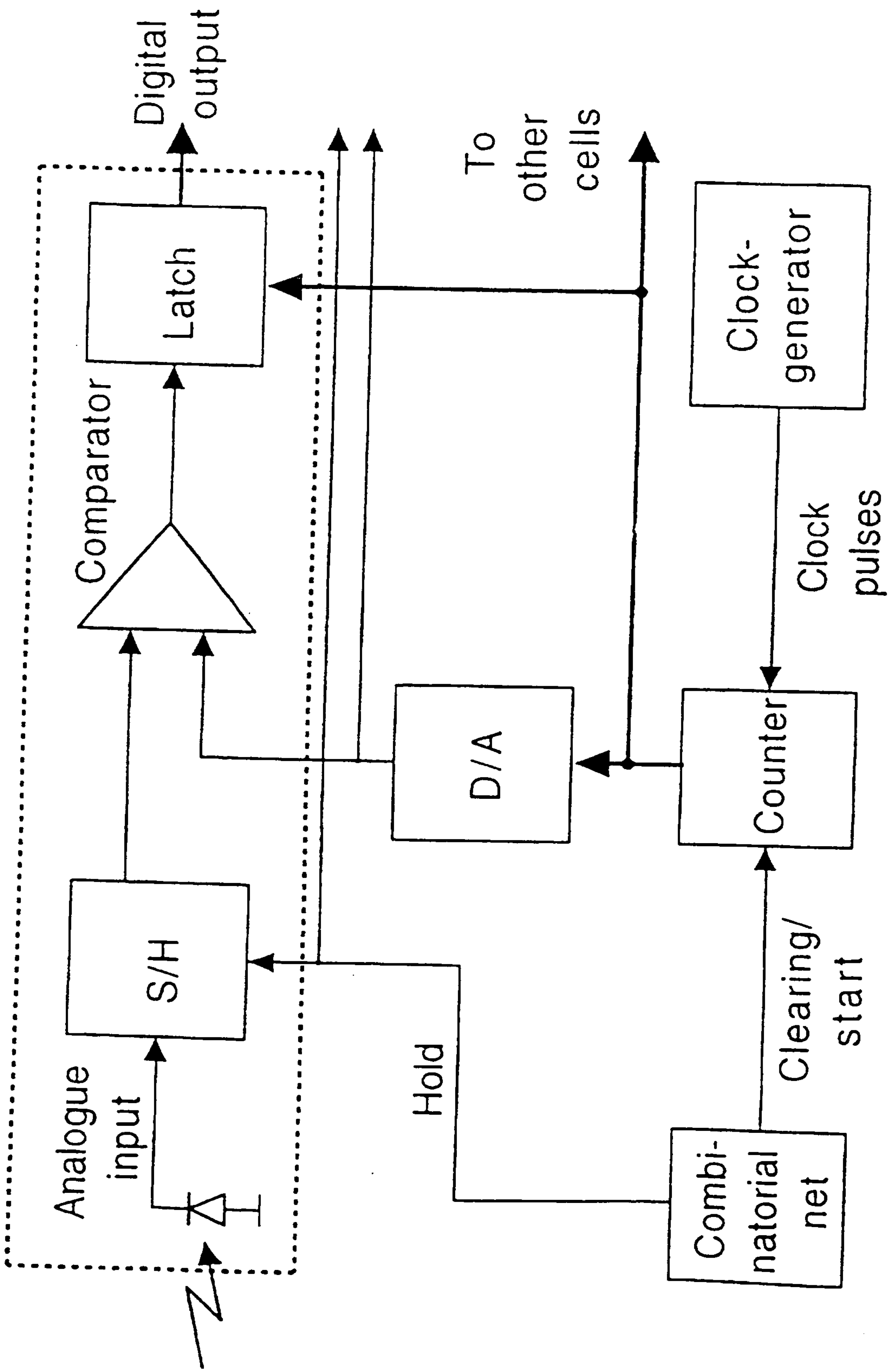

Digital output
To other cells
Latch
Comparator
Clock-generator
Clock pulses
D/A
Counter
S/H
Analogue input
Hold
Clearing/ start
Combi-natorial net

Fig 1

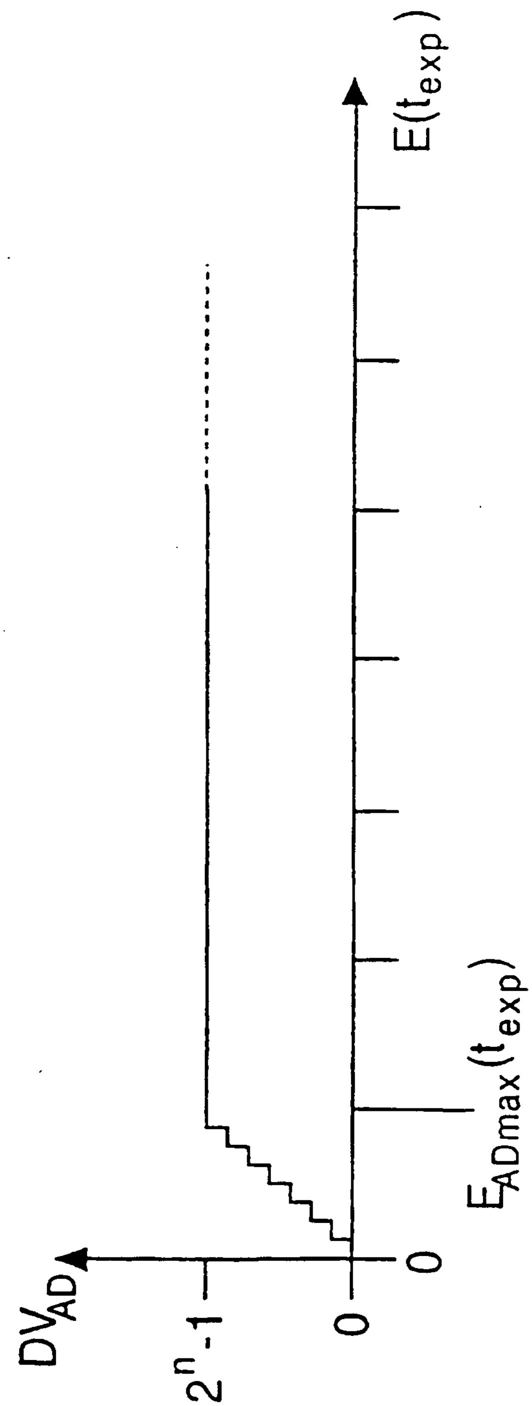
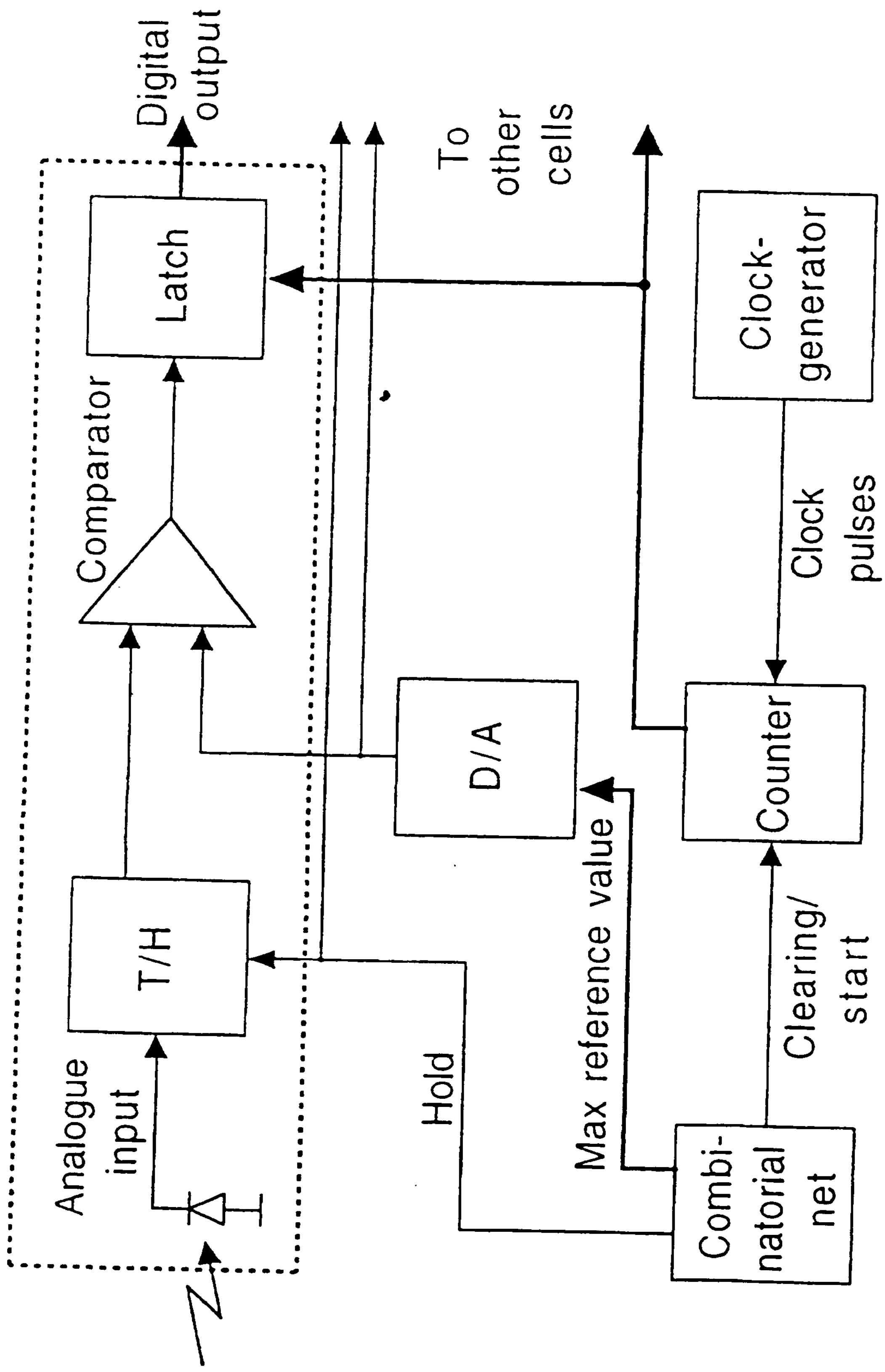


Fig 2



Digital output
Latch
Comparator
To other cells
Clock-generator
Clock pulses
D/A
Counter
T/H
Analogue input
Hold
Max reference value
Clearing/ start
Combi-natorial net

Fig 3

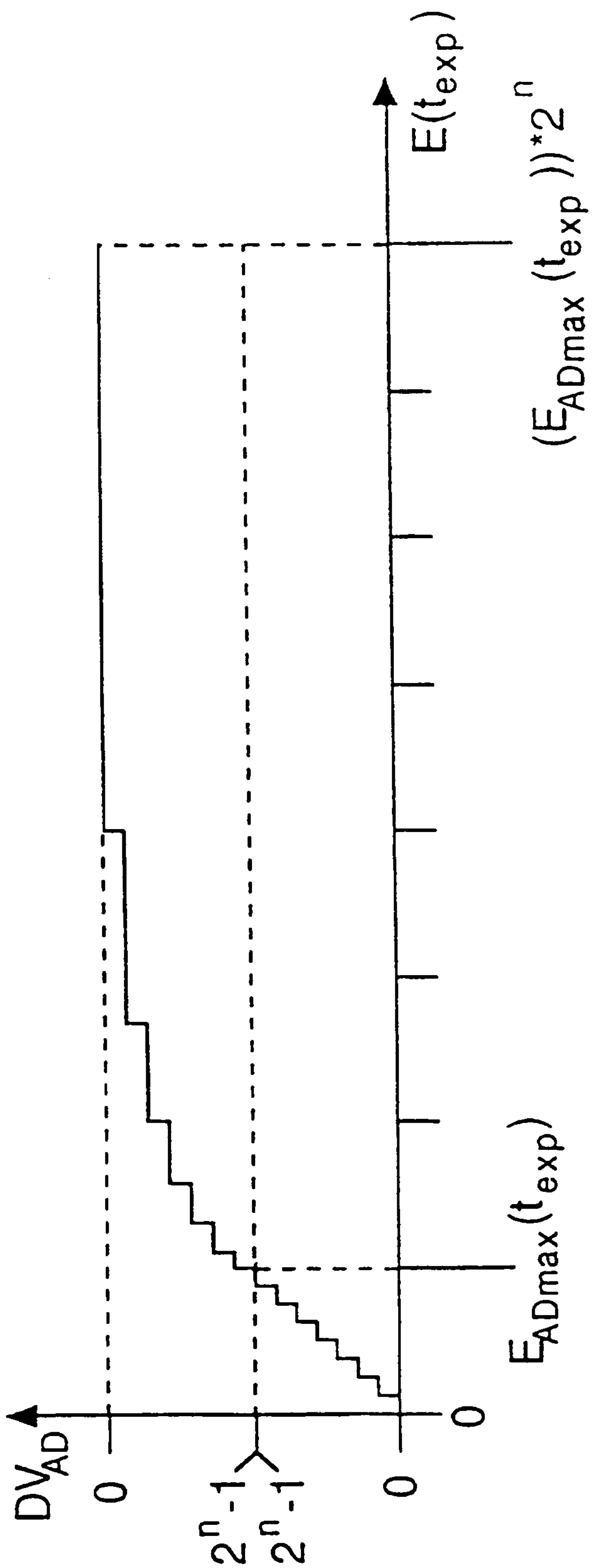


Fig 4

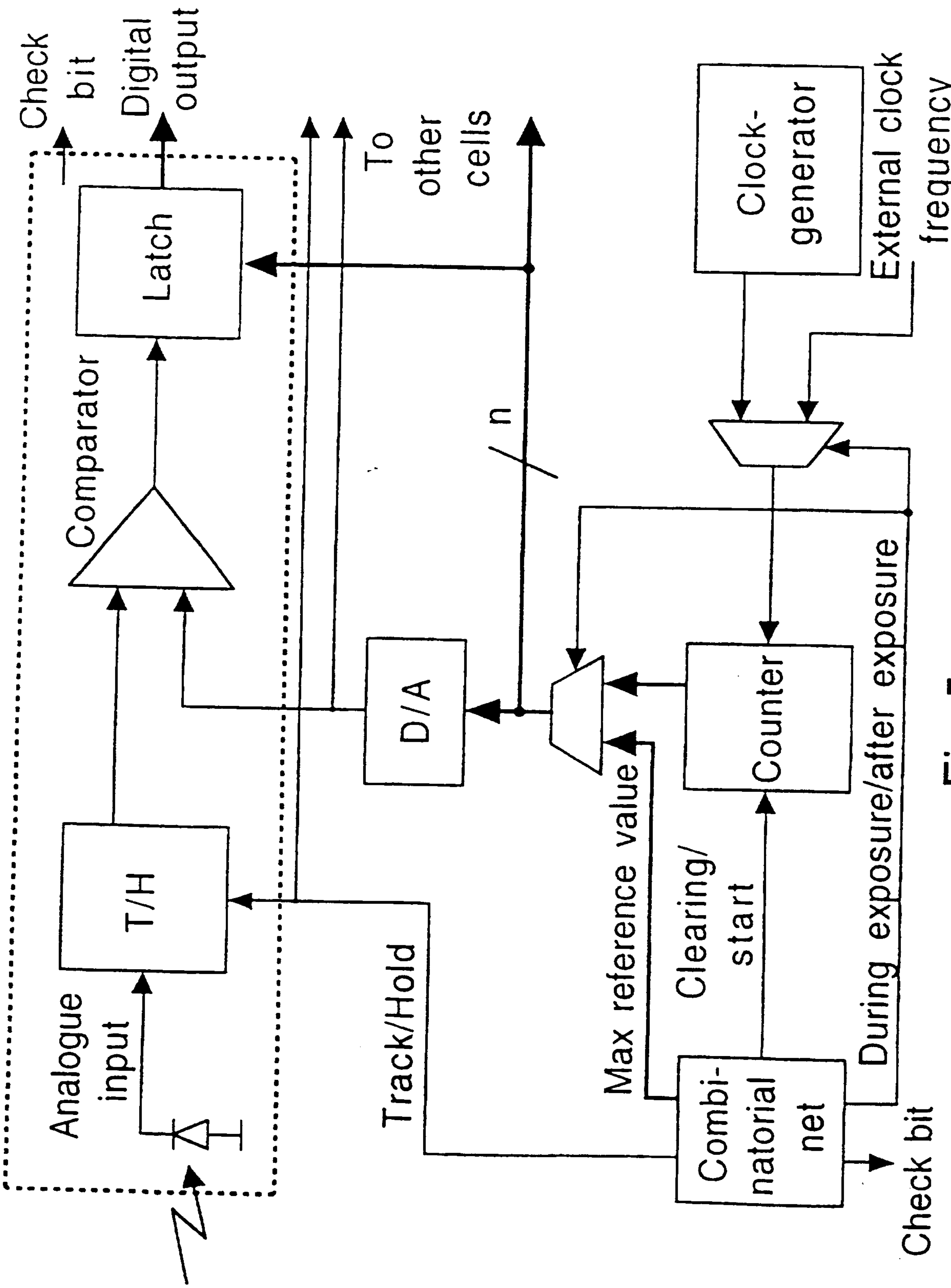

Check bit
Digital output
To other cells
Latch
Comparator
n
Clock-generator
External clock frequency
T/H
D/A
Counter
Analogue input
Track/Hold
Max reference value
Clearing/start
During exposure/after exposure
Combi-natorial net
Check bit

Fig 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 97/00442

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H03M 1/46, G01J 1/44
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H03M, G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, CLAIMS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5084704 A (W.J.PARRISH), 28 January 1992 (28.01.92), column 3, line 28 - column 4, line 52, figures 1,2, abstract --	1-4
A	US 4940982 A (Z.GULZYNSKI), 10 July 1990 (10.07.90), column 1, line 64 - column 2, line 33; column 3, line 20 - column 5, line 27, figure 1, abstract --	1-10
A	EP 0372548 A2 (FUJITSU LIMITED), 13 June 1990 (13.06.90), figure 4, abstract --	1-10

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
9 June 1997	28.06.97
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International application No.
PCT/SE 97/00442

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	WO 9613903 A1 (FÖRSVARETS FORSKNINGSANSTALT), 9 May 1996 (09.05.96), figure 3, abstract -- --------	1-10

INTERNATIONAL SEARCH REPORT
Information on patent family members

03/06/97

International application No.
PCT/SE 97/00442

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5084704 A	28/01/92	NONE	
US 4940982 A	10/07/90	DE 3606893 A	10/09/87
EP 0372548 A2	13/06/90	CA 2004317 A,C	07/06/90
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WO 9613903 A1	09/05/96	AU 3857695 A	23/05/96
		SE 502900 C	19/02/96
		SE 9403736 A	19/02/96